IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of	RICHAUD, Johan L. et al.
Title	MULTI-OUTLET CASTING NOZZLE
Serial Number	10/579,858
Filing Date	May 17, 2006
Art Unit	1793
Examiner	Kastler, Scott R.
Attorney Docket No.	1463 US/PCT

To: Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

AFFIDAVIT UNDER 37 C.F.R. § 1.132

I, Johan Richaud, hereby swear and state that:

1. I have been active in research and development in the field of fluid mechanics as applied to the flow of liquid metals, and in particular as applied to the flow of molten, i.e., liquid, steel for the last 8 years.
2. I am currently an employee of the Vesuvius Group, which manufactures a broad range of refractory products for molten metal flow control and containment, and has greater than $1 billion in worldwide refractory sales.
3. I received an Engineering degree in technical ceramics and glasses , equivalent to a master degree in Ceramic Science, from E.N.S.C.I. - a three-year National School of Engineering - Limoges, France in 1995.
4. I am the author or co-author of technical papers, presented at meetings and symposia, relating to liquid metal flow and iron and steel production.
5. I hold four US patents and many foreign patents, particularly relating to refractory articles and related processes used in the steel making and steel casting industries.

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6. I am very familiar with the dynamics of steel casting and how molten metal flows through the entire casting process.

7. I have conducted numerical simulations of flow patterns of molten metal, have witnessed the use of refractory articles in commercial operation, and am very familiar with the problems arising in various refractory articles.

8. I am co-inventor of the subject matter described in the present application, U.S. Patent Application No. 10/579,858 ("the '858 application"), which was published as U.S. Patent Publication No. 2007/0102852.

9. I have read and reviewed U.S. Patent No. 4,949,778 to Saito et al., and have found that the product described therein differs from the product of the present invention.

10. In the product of Saito et al. the total area of all outlets is not less than twice the sectional area of the molten steel passage corresponding to the central bore of the present invention. In the product of the present invention, the total area of all outlets is less than twice the cross-sectional area of the central bore. The configuration of the present invention has been found to have the unexpected results of reducing clogging and of reducing mold level fluctuations.

11 I have read and reviewed European Patent Publication No. EP0852166 to Centro Sviluppo Materiali S.p.A. ("EP '166), and have found that the product described therein differs from the product of the present invention.

12. EP '166 teaches a product in which each outlet of the at least two first outlets has a prevalently upward direction, and in which each outlet of the at least two second outlets has a prevalently downward direction. In the product of the present invention, all discharge outlets are directed at an angle not greater than 90 degrees with respect to the longitudinal axis of the nozzle, measuring from the end directed towards the closed end of the bore.

13. In the EP '166 product, the flow from the outlet directed in a prevalently upward direction and the flow directed in a prevalently downward direction interfere with each other. The result is turbulence in the molten metal, leading to defects and inclusions in the product. In the product of the present invention, this turbulence and the resulting faults are reduced or eliminated.

14. I have performed computational simulations for the comparison of a conventional product of the prior art, the Saito et al. product and the EP '166 product with the product of the

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present invention. For the simulations, all 4 Submerged Entry Nozzles (SENs) were given the same upper bore diameter, 75mm. The lower bore diameter and the port dimensions differ for the various products. The design of the present invention is the only design having a total port area less than twice the upper bore cross sectional area. The design of the present invention is the only design having a ratio of lower port to upper port area greater than one. Information not specified is designated "NA".

Design Features	Conventional Design	EP '166	Saito et al.	Present Invention
Upper Bore Diameter (mm)	75	75	75	75
Lower Bore Hydraulic Diameter (mm)	75	65	67	55
Ratio Lower/Upper Bore Diameter	1	0.75	0.80	0.73
Top Port Angle from Horizontal (Degrees)	NA	-15	0	-10
Bottom Port Angle from Horizontal (Degrees)	-15	15	-15	-15
Ratio of Total Port Area to Upper Bore Section Area	2	3.14	>2	<2 and >1
Ratio of Upper Port Area to Upper Bore Section Area	NA	1.69	>1	0.9
Ratio of Lower Port Area to Upper Bore Section Area	2	1.45	>1	1.0
Ratio of Lower Port Area to Upper Port Area	NA	0.85	~1	1.17
Top Port Height (mm)	NA	69	30	30
Bottom Port Height (mm)	75	63.75	40	35
Top Port Width (mm)	NA	69.00	75	66
Bottom Port Width (mm)	75	63.75	67	66
Ratio of Bottom Port Height to Top Port Height	NA	0.92	1.33	1.17
Ratio of Top Port Height to Top Port Width	NA	1.00	0.40	0.45
Ratio of Bottom Port Height to Bottom Port Width	1	1.00	0.60	0.53

15. The simulations were conducted with the same criteria for each product: a mold width of 1500 mm, a mold thickness of 220 mm, port submergence of 120 mm, and SEN diameter of 125 mm. The results of these simulations are summarized in the following table:

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Flow features	Conventional Design	EP '166	Saito et al.	Present Invention
Maximum sub-meniscus velocity (meters/second)	0.55	0.46	0.26	0.32
Maximum wave height (mm)	12.31	8.30	5.07	7.47
Maximum meniscus turbulence intensity (%)	13.44	9.20	5.80	10.11
Maximum meniscus vorticity magnitude (1/s)	217	106	65	115
Impact point on narrow face (mm from meniscus)	0.2	0.25	0.3	0.3
Maximum impact velocity in narrow face (m/s)	0.37	0.32	0.39	0.32

16. Both the conventional design and the EP '166 design produce excessive sub-meniscus velocities. The molten mold powder, protecting the liquid steel from re-oxidation, can be re-entrained when the sub-meniscus velocity exceeds 0.45 to 0.5m/s. An excessive amount of hot metal is directed towards the meniscus in this case. The upper re-circulation flow is activated by high turbulence in the port region. In the case of the EP '166 configuration, the two jets exiting the ports are interacting with each other generating powerful eddies that promote curling of the jet towards the meniscus. Consequently the wave height is greater than the desired range (3 - 8mm). The impact location along the narrow face is also too high.
17. In the Saito et al. design, the sub-meniscus velocity is too low to insure an optimal thermal distribution along the meniscus region. The Saito et al. inventors teach that the use of an EMBR (Electro-Magnetic Brake) is required to promote a greater delivery of hot metal towards the meniscus. Also, the strength of the bottom port jet is too high in this design, leading to too much flow being deflected downwards along the narrow face and to a high impact velocity on the narrow face. The turbulence intensity along the meniscus is too low to promote optimal mold powder melting and oxide absorption. The interface between the steel and the molten powder is too quiet.
18. Compared to the conventional design, the EP '166, Saito et al. and present invention port designs reduce the maximum vorticity along the meniscus.
19. The port design of the present invention produces an optimal mold flow, with wave height, maximum sub-meniscus velocity, turbulence intensity and impact location along the

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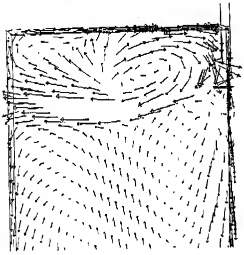
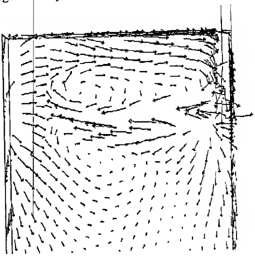
narrow faces with the desired ranges. These ranges have been determined after extensive water modeling, computational simulations and field measurements.

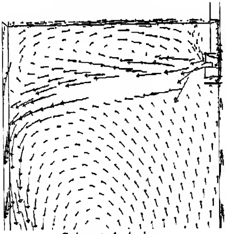
20. I have derived the following velocity vector graphs for the conventional design, the EP '166 design, the Saito et al. design and the design of the present invention.



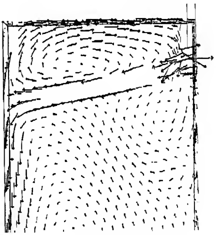
Conventional design



EP '166 design



Saito et al. design



Present invention

21. The velocity vector graphs for the conventional design and the EP '166 design exhibit strong re-circulation vortices promoting excessive delivery of hot metal towards the meniscus.

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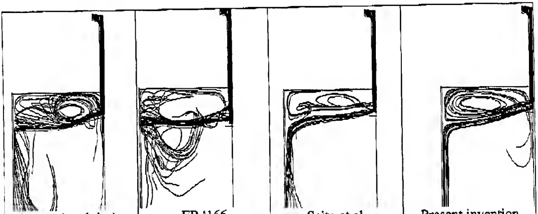
22. The velocity vector graph for the design of Saito et al. exhibits strong deflection along the narrow face. Not enough hot metal is directed towards the meniscus to ensure proper mold powder melting and desired inclusion floatation.

23. The velocity vector graph for the design of the present invention exhibits a desirable pattern of high stability mold flow and weak re-circulation vortices.

24. I have prepared graphs showing the flow path lines or streamlines of fluid in the flow regulation region for each of the four designs. The designs being compared exhibit two symmetry planes, so it is sufficient to model one-fourth of the mold and casting channel.



Conventional design	EP '166	Saito et al.	Present invention

25. The flow path lines of the conventional design exhibit early jet curling producing an excessive sub-meniscus velocity

26. The EP '166 design displays a very unstable jet due to the unpredictable interaction of the upper and lower port jets.

27. The weak upper jet of the Saito et al. design produces a limited amount of hot metal delivered towards the meniscus.

28. The present invention produces stable, compact jets. The upper jet directs the desired amount of hot metal towards the meniscus.

29. I have prepared plots showing the sub-meniscus velocity distribution along the meniscus free surface for each of the four designs. The position $x = 0$ corresponds to the center of the SEN. The position $x = -0.75$ corresponds to the narrow face.

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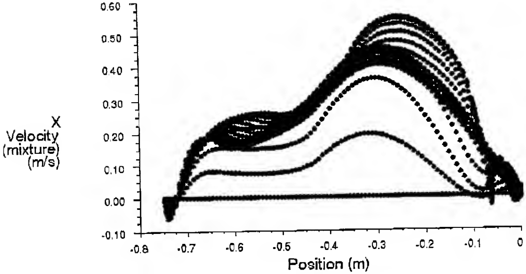
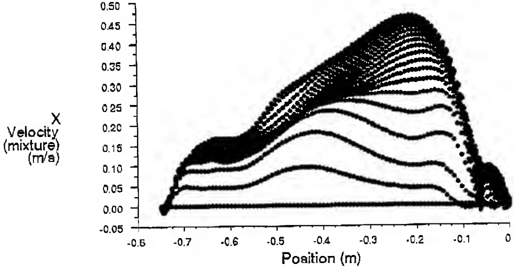


Conventional design



EP '166

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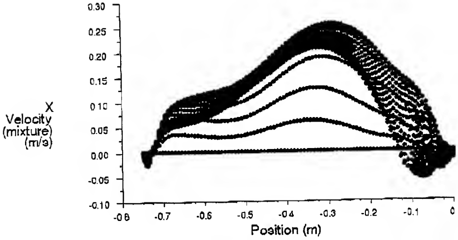
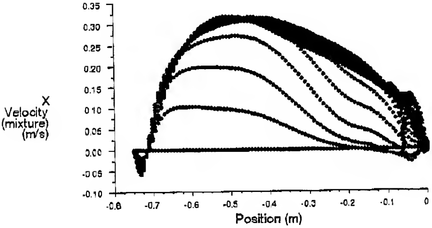


Saito et al.



Present invention

30. The peak of the maximum sub-meniscus velocity is too close to the SEN for the conventional, EP '166 and Saito et al. configurations. Vortexing and mold powder re-entrainment may occur.
31. In the configuration of the present invention, the sub-meniscus velocity is well distributed along the meniscus, thus preventing undesired fluctuations and vortexing near the SEN.

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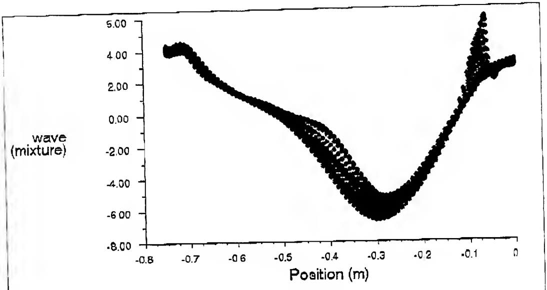
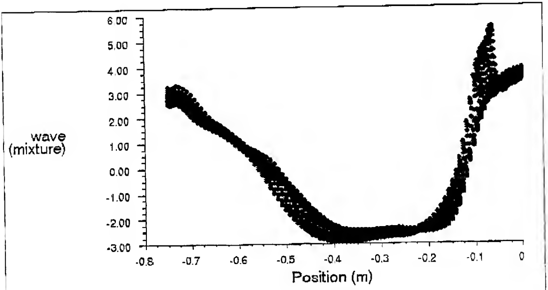
32. I have prepared plots showing the shape of the meniscus free surface for each of the four designs. The position x = 0 corresponds to the center of the submerged entry nozzle (SEN). The position x = -0.75 corresponds to the narrow face.



Conventional design



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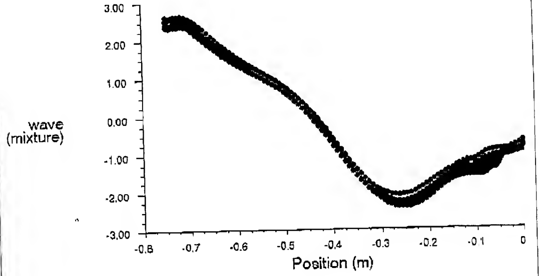
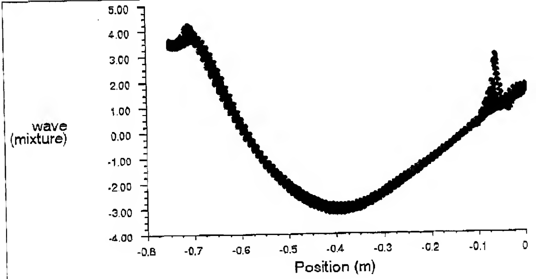


Saito et al.



Present invention

33. The present invention produces a meniscus shape that has the advantage of being smooth and symmetrical around the 1/4 point of the slab.

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34. I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the above-referenced application or any patent issuing thereon.

Date: 03/03/2009

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Johan Richaud

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